Prediction of the Low Frequency Wave Field on Open Coastal Beaches

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LONG-TERM GOALS

The long-term goal of this study is to arrive at a predictive understanding of the time varying circulation in the nearshore region given only information about the incident wave field and bottom bathymetry. Predictions should include information about the kinematics of low frequency motions (their wavenumbers and frequencies) as well as information about their dynamics (energetics).

OBJECTIVES

The scientific objectives of the study are related to gaining an understanding of the important features of the nearshore circulation field, so that quantitative predictions about the circulation field at a given site can be reliably made. Specific objectives include: 1. The assessment of the impact of specific features of wave groups on edge wave development and the prediction of the finite amplitude edge wave field resulting from a balance between the wave group forcing and dissipation mechanisms. 2. The assessment of the degree to which non-uniformities in the bottom bathymetry (both abrupt and gradual) affect the resulting low frequency wave climate. 3. The assessment of the importance of interactions between different modes of time-varying motions in the nearshore region, as well as interactions between these modes and the incident wave field. 4. To arrive at a predictive understanding of low frequency motions.

APPROACH

The approach is to use a numerical model to assess our understanding of time-varying circulation in the nearshore region. The finite amplitude behavior of low frequency motions in the nearshore region is a function of a balance between processes that generate these motions and processes that dissipate them. The approach used here is to isolate several generation, dissipation processes as well as processes affecting the evolution of the motions in a modeling effort and start with the simplest possible theory to model the processes. More complicated and full treatments are introduced in a step-by-step fashion resulting in an understanding of the effects of the processes and their parameterizations on the resulting circulation field. In the final stages of the project we will test our predictive capabilities by simulating the actual situation during the DELILAH field experiment. Measurements will be used to specify the incident wave forcing function and bathymetry. The computed time-varying circulation field will be compared to measurements.

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We are utilizing a model that solves the time-dependent shallow water equations with additional terms to account for the effects of forcing and damping (Özkan-Haller and Kirby, 1997). Although only valid in shallow water, these equations can model the leading order behavior of both low frequency gravity motions (edge waves) and vorticity motions (shear waves). Eight partial differential equations are solved simultaneously to obtain the evolution of eight unknowns; namely, the phase-averaged water surface elevation, the phase-averaged cross-shore and longshore velocities, the horizontal shoreline runup, the incident wave energy, the incident wave wavenumber, the local incident wave direction, and the water depth. The effects of bottom friction, turbulent momentum mixing, incident wave transformation and forcing, wave-current interaction and arbitrary bottom movement, are included in a rudimentary fashion. We begin our modeling effort by generating edge waves and shear waves in idealized conditions, and progressively move to more realistic situations where these motions are allowed to coexist and interact.

WORK COMPLETED

We have completed the implementation of an equation governing the behavior of the time-varying incident wave energy in order to simulate the evolution of incoming wave groups. We subsequently analyzed the generation of edge waves by a bi-chromatic wave field, including the effects of nonlinear wave interactions as well as the effect of a moving breakpoint (Lippmann *et al*., 1997). We successfully generated various edge wave modes of finite amplitude. We are currently working on isolating the effects of nonlinear generation mechanisms and generation due to a moving breakpoint. Also under investigation is the half-life of the generated waves.

We have completed the implementation of the time dependent equations that approximate the behavior of phase-averaged properties of the incident waves; namely, the incident wave energy, the wavenumber and the local angle of incidence. The energy equation for the incident waves is used to model the former while the conservation of wavenumber principle is introduced to model the latter two variables. These model equations include effects of the current velocities. In this manner the forcing of wave-induced currents is modeled while taking the effects of the generated currents on the wave field into account. We have analyzed wave-current interaction effects in environments with varying amounts of dissipation due to bottom friction. We concentrated on the flow properties of the resulting currents as well as propagation speeds of the resulting motions. Also of interest was the effect on the shoreline runup.

We have begun work on an analytical model to isolate unstable behavior in the surf zone due to the interaction of unsteady currents and the incident wave field. Utilizing this linear instability model we are searching for unstable behavior in a system that includes unsteady currents as well as an unsteady wave field due to the effects of the currents on the incident waves.

RESULTS

Computations of the instability climate for a barred beach show that the shear instabilities of the longshore current have significantly altered finite amplitude behavior when wave-current interaction effects are included. We analyzed these effects in environments involving varying amounts of bottom friction. The primary effect of the interactions is a reduction of the extent of the motions in the offshore direction. The energy content of the motions within two surf zone widths is not significantly altered but the general character of the flow features appears to be strongly affected by the inclusion of wave-

current interaction. We found that this effect is more pronounced for cases involving low frictional dissipation. Figure 1(a) shows a snapshot of the vorticity field when wave-current interaction is neglected in an environment with low frictional dissipation. The shoreline is located at *x*=0 and *x* points offshore while *y* points alongshore. The nearshore bar is located 100 m offshore of the shoreline, and the shear waves can be observed to affect a region that extends about 200 m offshore. Vortex pairs are occasionally released towards the offshore and can be observed at approximately *x*=250 m. There are also areas over the bar (e.g. around *y*=100 m) where offshore directed currents can be observed. These currents can exceed 0.3 m/s. Figure 1(b) shows a snapshot of the vorticity field obtained while including wave-current interaction. The primary effect of the interactions is a reduction of the extent of the motions in the offshore direction. No vortex pairs appear to have been shed offshore during this simulation. The energy content of the motions within two surf zone widths is not significantly altered but the general character of the flow features appears to be strongly affected by the inclusion of wave-current interaction.

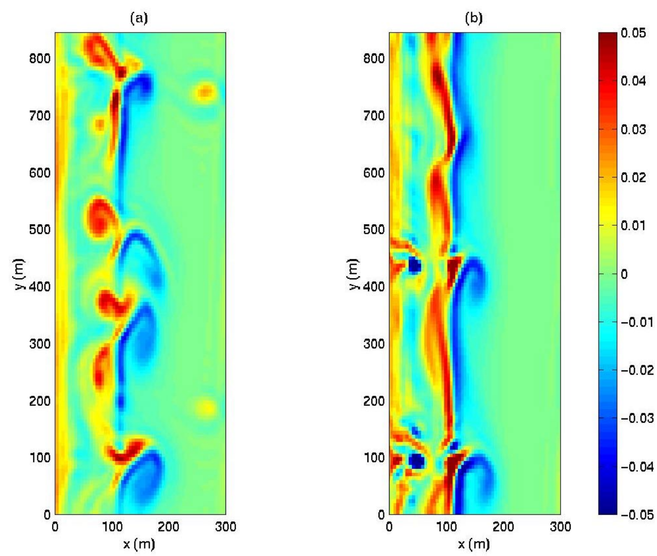

Figure 1: Snapshots of vorticity for shear instabilities on a barred beach with low frictional dissipation (c_f=0.004) (a) neglecting and (b) including wave-current interaction.

A second effect of wave-current interaction is that the resulting flow features have a faster propagation speed. We find that this effect is most pronounced in cases involving high frictional dissipation. Although the propagation speeds for cases involving high frictional dissipation varied by as much as 40% (see Figure 2), cases involving low frictional dissipation showed minimal change in the propagation speeds (see Figure 3).

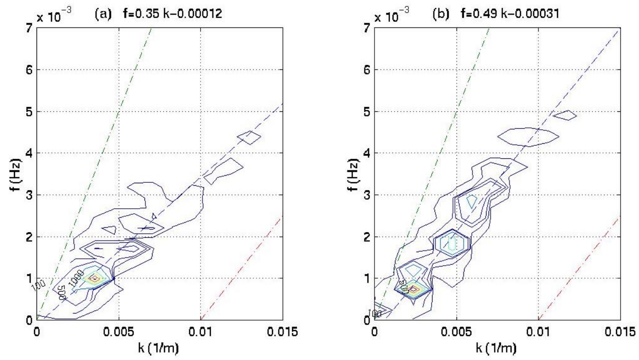

Figure 2: Frequency-longshore wavenumber spectra of the longshore velocity signal (a) neglecting and (b) including wave current interaction (c_f=0.006). The equation for the best-fit dispersion line is shown above each plot

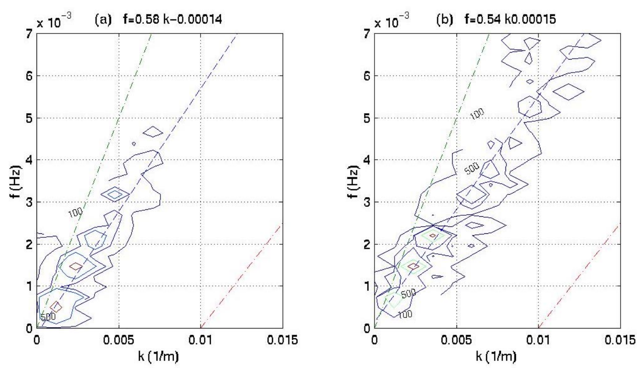

Figure 3: Frequency-longshore wavenumber spectra of the shoreline runup signal (a) neglecting and (b) including wave-current interaction (c_f=0.004). The equation for the best-fit dispersion line is shown above each plot.

We have also analyzed the effects of wave-current interaction on the shoreline runup. Visual inspection of Figure 1 shows that the shoreline jet is more active when wave-current interaction is considered. Closer inspection of the frequency-wavenumber spectrum associated with the horizontal shoreline runup (Figure 3) shows that the frequency range of the shoreline runup increases dramatically. The energy content of the shoreline motions also increases significantly. This finding should be viewed in light of observations by Holland and Holman (1999) who found significant energy in the shoreline runup spectra that can be attributed to shear waves in spite of the fact that shear waves had previously been shown to have minimal surface elevation signals associated with them. Our findings suggest that wave-current interaction close to the shoreline may be responsible for detectable shoreline excursions due to shear waves. This notion is also supported by visual observations of the wave field close to shore in the presence of instabilities by Reniers *et al* (1997), who reported strongly distorted wave crests very close to shore. Such distortions can, once again, be the result of wave-current interactions in this region.

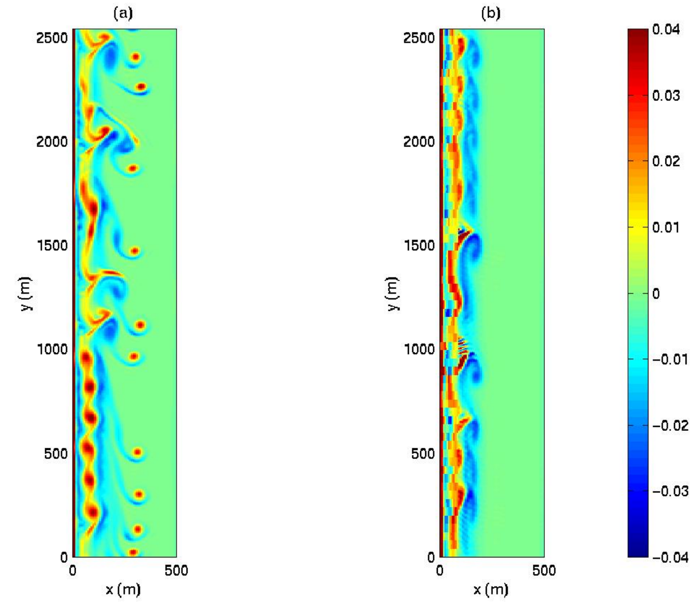

Figure 4: Snapshots of vorticity for SUPERDUCK (c_f=0.0035, M=0.25) (a) neglecting (b) including wave-current interaction. The vorticity fields were filtered to eliminate high frequency components.

We have applied the model equations including the effects of wave-current interaction to a more realistic case. In particular, we show preliminary results obtained utilizing measured bathymetry and incoming wave field during the SUPERDUCK field experiment. Previous simulations for this experiment had been carried out neglecting the effects of shoreline runup and wave-current interaction (Özkan-Haller and Kirby, 1999). A snapshot of vorticity for simulations for realistic friction and mixing coefficients including the shoreline runup, but still neglecting the wave-current interactions, are shown in Figure 4(a). The flow features exhibit properties of a turbulent shear flow that affects a region extending multiple surf zone widths offshore. Figure 4(b) shows the spatial character of shear instabilities when wave-current interaction is considered. We note that the offshore extent of the motions is once again reduced. We are currently investigating the extent to which inclusion of wave-current interaction in the modeling scheme affects data-model comparisons.

IMPACT/APPLICATIONS

This study will shed light on the processes that are important in the low frequency range of the energy spectrum, such as interactions between low frequency waves and response of the low frequency environment to external forcing. This study can also serve as a benchmark for other studies that do not explicitly resolve the time-varying low frequency wave field but instead focus only on the mean circulation. Results obtained here should also be relevant to studies that are not restricted to low frequency motions, but where the low frequency motions are embedded in higher frequency oscillations, making the processes difficult to identify.

TRANSITIONS

The work on the project will lead to a robust modeling tool which is capable of predicting the time-varying circulation field including effects such as incident wave forcing, bottom friction, momentum mixing and wave-current interaction. The model code is available to the engineering and science communities.

RELATED PROJECTS

The effect of edge waves and shear waves on the evolution of bathymetry is being investigated as part of the ongoing NOPP project (Lead P.I. J.T. Kirby) "Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean". A version of the code developed here is utilized in the project "Modeling Beach Morphology Changes Coupled to Incident Wave Climate and Low Frequency Currents" (P.I. J.T. Kirby). Aspects of unsteady currents in the nearshore zone are the topic of the study "Nonlinear Time-Dependent Currents in the Surfzone" (P.I. D. Slinn).

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